Occurrence of severe geomagnetic storms and their association with solar–interplanetary features

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Abstract. Severe geomagnetic storms are observed to be the largest 2% of all large geomagnetic storms. Here great geomagnetic storms with Dst magnitude < -200 nT are considered. In this paper all severe geomagnetic storms have been selected which have occurred during year 1996 to 2005.We have found 16 severe geomagnetic storms during this period. These storms are significant not only because of the extremely high magnetic activity but also due to their great impact on the geomagnetosphere. The relationship of severe geomagnetic storms with different interplanetary parameters and their solar source origin are presented. We have found that 95% severe geomagnetic storms are associated with halo coronal mass ejections.

Index Terms. Coronal mass ejections, interplanetary features, large geomagnetic storms.

1. Introduction

Solar output in terms of solar plasma and magnetic field ejected out into interplanetary medium consequently create the perturbation in the geomagnetic field. When these plasma and fields reach the Earth's atmosphere, they produce extra ionization in the sunlit part of the Earth and exhibits peculiar storm time charges in the observed geomagnetic field. Solar wind plasma constantly flowing out of the sun throughout interplanetary space at typical speeds of the order of 400–500 km/s, carrying the Sun's magnetic field frozen into it (Brandt, 1970). Superposed on this ambient plasma there are transient injections of material, often faster than the solar wind and also carrying strong magnetic field, known as coronal mass ejections. Earth's magnetic field, shielding Earth from a variety of interplanetary structures, forms the cavity known as magnetosphere. If the solar wind magnetic field is such that its direction points anti–parallel to Earth's magnetic field, energy can be injected into the magnetosphere, increasing the equatorial ring current, causing geomagnetic storms. Large geomagnetic storms are usually caused by structures in the solar wind having specific features : long durations of strong southward interplanetary magnetic field (IMF) impinging on the Earth's magnetosphere. These features are effective in causing geomagnetic disturbances and are said to be geoeffective (Chen, 1996; Chen et al., 1996). Large geomagnetic storms can cause deleterious effects on space and ground based installations. The variation of Earth's magnetic field, usually expressed through magnetograms, shows the time variation of declination (D), vertical component (Z) and horizontal component (H). However, for global quantitative representation, various geomagnetic indices have been introduced. The disturbances storm time (Dst) index is the conventional measure of ring current intensity and energy observed at Earth's surface over low and moderate latitudes. The Dst values are obtained from the longitudinal average of H variations measured at middle and low latitude observatories. It is the best indicator of the ring current intensities and a very sensitive index to represent the degree of solar disturbances. The aim of the statistical study presented in this paper is to analyze various characteristics of severe geomagnetic storms and their association with different solar–interplanetary features for the solar cycle 23.

2. Selection criteria and data analysis

A catalogue of severe geomagnetic storms (Table–1) that occurred during 1996–2005, has been compiled. In the present study, we have analyzed in detail all those large geomagnetic storms which are associated with Dst decreases of less than –200nT and are observed during the period 1996–2005. If the magnitude of storm (Dst value) recurs for several consecutive days / hours, then the last day / hour is taken as the storm day. A set of 16 severe geomagnetic storms associated with Dst $\leq$ - 200 nT are presented. We have also analyzed association of such a storms with different solar and interplanetary disturbances. The hourly values of geomagnetic index, Dst, has been obtained by Solar Geophysical Data (Prompt and comprehensive report) of U.S. Department of commerce, NOAA (monthly issue) and Omni data services. The data of coronal mass ejection has been obtained from the website www.cdaw.gsfc..nasa.gov/CME_list. During the aforesaid period, we find 16 severe geomagnetic storms falling under the selection criteria. The list of these selected geomagnetic storms and their characteristic features are summarized in Table 1.

Table 1. Characteristic Features of Severe Geomagnetic Storms occur during Solar Cycle 23

Date of event	Time of event	Max. mag. of event (nT)	Initial phase duration (hr.)	Main phase duration	Recovery phase duration (hr.)	Longi-vity	Type of storm	| B |	Bz	V Km/s.	Kp* 10	Ap	CME association (Km/s)	Type of CME
04.05.98	6 UT	-216	46	4	298	348	S	38.7	-29.6	867	87	-	CME (871)	Halo CME
25.09.98	10 UT	-233	3	6	16	25	S	29.5	-17.5	901	83	117		
22.10.99	6UT	-231	7	6	95	108	S	35.9	-30.7	692	80	-	CME (700)	Partial Halo
07.04.00	1UT	-321	8	5	138	151	G	31.4	-27.5	571	83	82	CME (1927)	Halo CME
15.07.00	22UT	-300	3	2	91	96	S	31.8	-21.2	691	80	164	CME (1147)	Halo CME
12.08.00	10UT	-237	45	8	105	158	G	31.6	-28.9	613	77	123	CME (999)	Halo CME
31.03.01	9UT	-358	9	4	80	93	G	43.1	-40.3	671	87	192	CME (1147)	Halo CME
11.04.01	23UT	-256	1	6	93	100	S	34.5	-20.5	725	83	85	CME (2975)	Halo CME
06.11.01	6UT	-277	17	9	147	173	S	-	-	-	-	142	CME (1691)	Halo CME
24.11.01	15UT	-212	22	9	77	108	S	21.2	13.5	876	73	104	CME (1409)	Halo CME
30.10.03	23UT	-401	24	39	29	92	S	-	-	-	-	191	CME (1519)	Halo CME
20.11.03	20UT	-472	17	9	85	111	S	33.1	-27.5	566	87	150	CME (1656)	Halo CME
08.11.04	7UT	-373	5	6	20	31	G	24.2	-12.6	719	83	140	CME (1689)	Halo CME
10.11.04	10UT	-289	16	9	76	101	S	18.7	-11.6	695	83	161	CME (1250)	Halo CME
15.05.05	8UT	-256	4	3	-	-	G	54.1	-13.2	845	83	-	CME (1759)	Halo CME
24.08.05	11UT	-219	2	1	57	60	G	-	-	-	-	-	CME (2000)	Halo CME

3. Characteristic features of severe geomagnetic storms

The characteristic features of all those severe geomagnetic storms, which are compiled in Table 1, are described here. Out of the 16 severe geomagnetic storms, 10 are sudden commencement type and the rest are gradual commencement type. Generally, it is believed that the majority of severe geomagnetic storms occur during the maximum phase of sunspot cycle, because many solar active regions appear during this time, while a few of the geomagnetic storms are observed during the minimum phase of sunspot cycle due to the presence of coronal holes and some other solar activities. During solar cycle 23 (1996-2005), the periods 1996-98 and 2003-05 are the periods of declining phase of solar activity, whereas the period 2000-01 to the maximum phase of solar activity.

Table 2. Occurrence of Severe Geomagnetic Storms during Solar Cycle 23

Year	Occurrence
1998	2
1999	1
2000	3
2001	4
2003	2
2004	2
2005	2

Table 2 shows that the majority of severe geomagnetic storms occurred during the maximum phase of the solar cycle.

In the following section we have discussed about some of the great events, illustrating the various features of solar–interplanetary and geomagnetic activity.

April 6–7 (year 2000) geomagnetic storm

Fig.1 is a composition of solar–interplanetary and geomagnetic observations from the 4^{th} to 10^{th} of April (2000). Graphs of magnetic field and plasma parameters observed by ACE, together with the Dst index. Interplanetary and geomagnetic parameters are presented. Soon after the shock "S" the Z component of magnetic field turns southward and is intensified because of a compression of sheaths region, remaining like that for approximately 18 hours, making the Dst index to fall to –321 nT. The total magnetic field jumps across the shock from 7 to 31 nT. The fast full halo CME speed observed to be around 1927 km/s. is the main cause to produce this severe storm (Gopalswamy, 2002)

July 15 –16 (year 2000) geomagnetic storms

Fig. 2 is similar to Fig. 1 but for the period of 14–17 July, 2000, and it shows the very well known 'Bastille day event". It consists of an interplanetary shock driven by magnetic cloud. While pointing southward it causes a very intense fall in the Dst index, reaching its minimum of –300 nT. A full halo CME, observed by the LASCO instrument with an speed of 1147 km/s associated with this severe geomagnetic storms.

October 22^{nd} (year 1999) geomagnetic storms

Fig. 3 shows the variation of various interplanetary geomagnetic parameters, for the period of 17–23 October 1999. The average magnetic field of the structure is of the order of 20 nT except at the rare part, where it jumps to around 36nT. At this rare position of the ejecta, the magnetic field was pointing substantially southward, thus causing the Dst to fall up to –237 nT. This event is very interesting, because the related CME observed by LASCO had an expansion of speed of 700 km/s which is considered a low speed, very close to the solar wind speed.

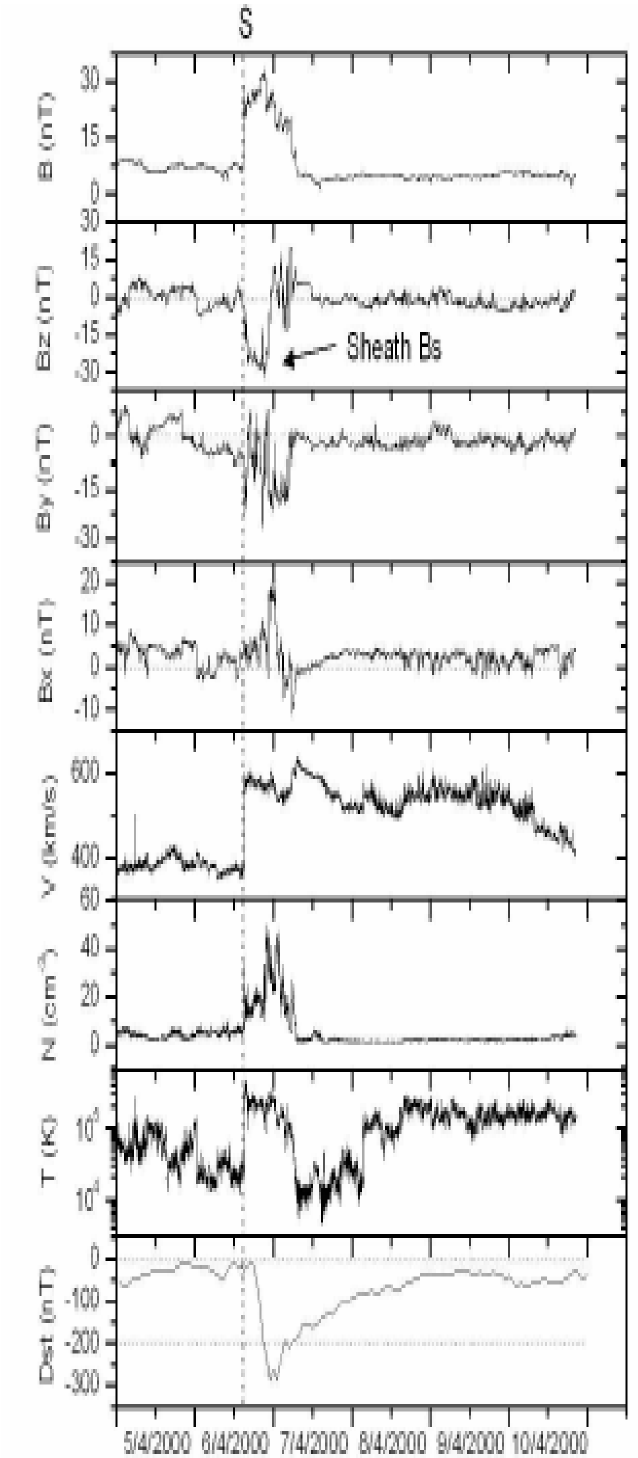

Fig. 1. Top to bottom : Interplanetary magnetic field and its 3 components, Bz, By and Bx, solar wind (proton) speed, number density and temperature and the Dst index for the period of April 5th to April 10th, 2000.

4. Discussion and conclusion

The 16 geomagnetic events considered in this paper, indicate various solar and interplanetary characteristics and their corresponding geomagnetic effects. For each event, peak Dst values as well as date and time of their occurrences, initial phase duration, main phase duration and recovery phase

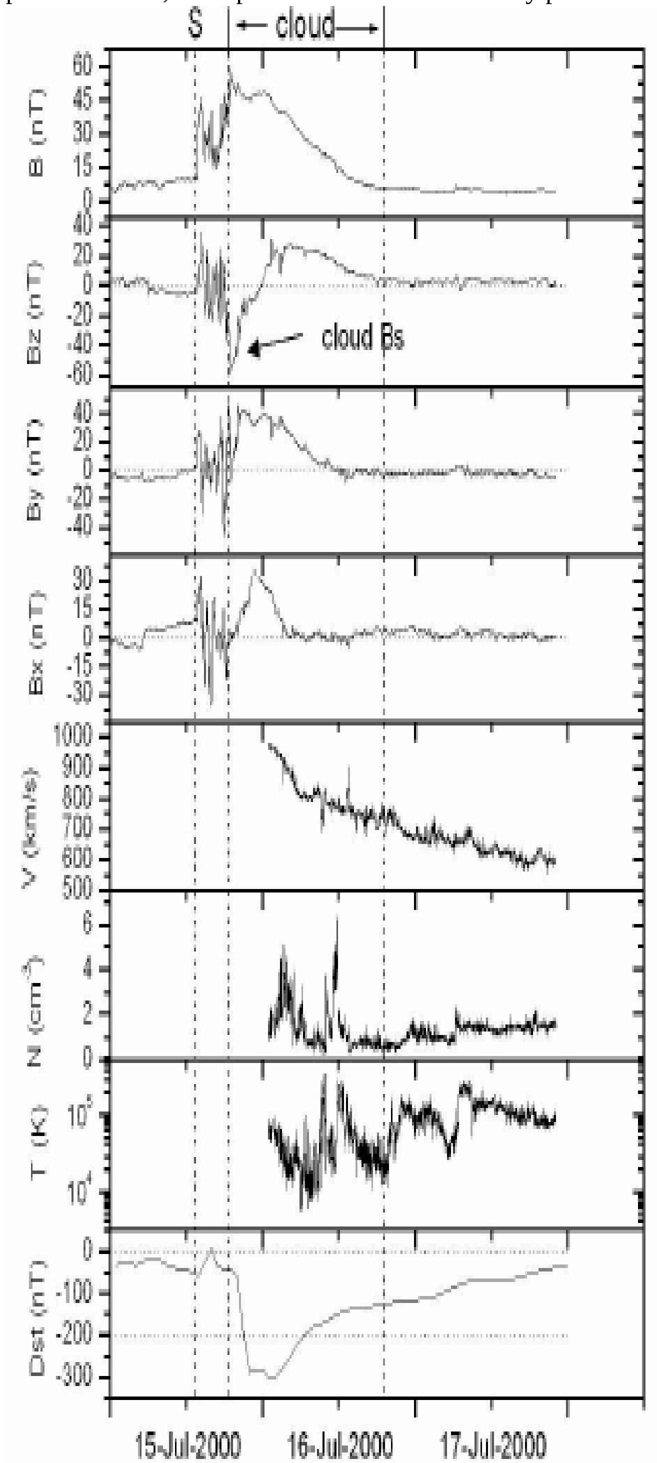

Fig. 2. Top to bottom : Interplanetary magnetic field and its 3 components, Bz, By and Bx, solar wind (proton) speed, number density and temperature and the Dst index for the period of July 15th to July 17th, 2000.

duration, longevity of storm, type of storms, total magnetic field, southward component Bz, velocity of solar wind, Kp*, Ap are presented. It is found that event of 20 November, 2003 with the Dst magnitude –472 nT is the biggest storm of the solar cycle 23 (Gopalswamy et al., 2005). The longevity of this storm in 111 hrs (about 5 days). This is the storm of sudden commencement type. The event is associated with full

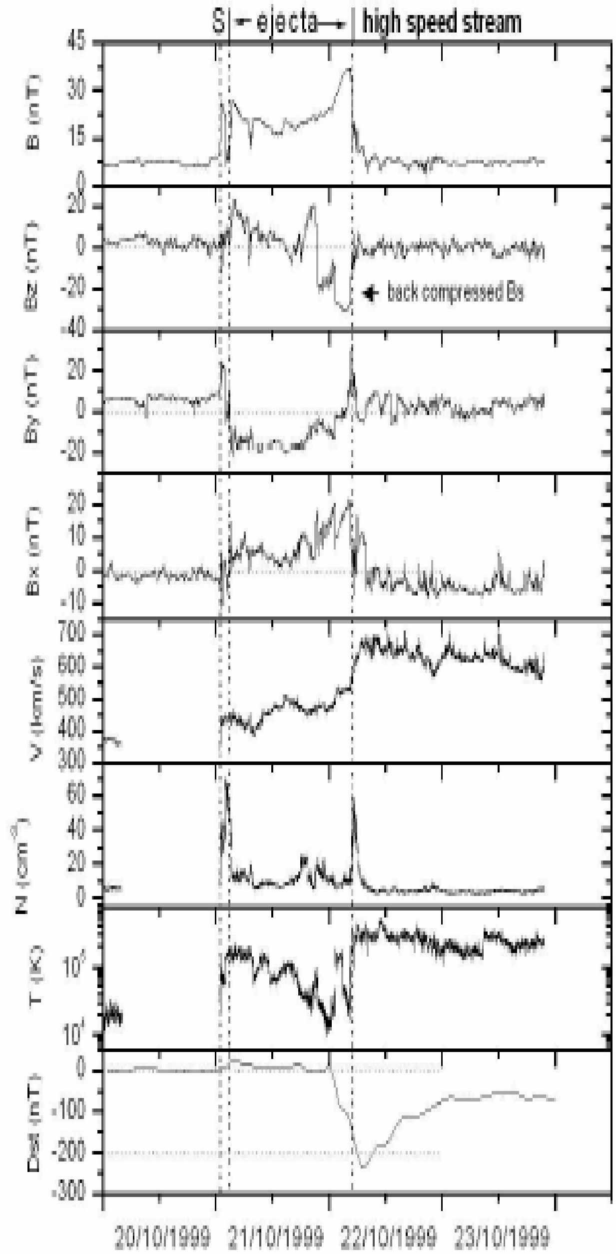

Fig. 3. Top to bottom : Interplanetary magnetic field and its 3 components, Bz, By and Bx, solar wind (proton) speed, number density and temperature and the Dst index for the period of October 20th to October 23rd, 1999.

Halo CME of speed 1656 km/s. Out of 16 severe geomagnetic storms, 14 storms are associated with full halos, spanning all around the solar disk, which means Halo CME is the main cause to produce severe geomagnetic storms (Tripathi et al., 2005). The 25th September, 1998 event with Dst magnitude –233 nT is associated with X–class flare but there was no CME observation because of temporary disability of SOHO. If we exclude this event, then all (100 %) severe geomagnetic storms are associated with halo coronal mass ejections.

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